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# A Historical Review of Technology Research in Special Education

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*In this article we review the research literature since 1980 on uses of technology in special education. Unlike past reviews, which have typically focused on academically related issues and the effectiveness of computer-assisted instruction, this review also summarizes the extensive observational and naturalistic studies, as well as research efforts in technology-based assessment. This diversity of research in special education stems from the multiple roles of the special education teacher, who, in addition to bearing instructional responsibilities, often determines eligibility for services, tracks progress toward IEP goals, and facilitates a student's day-to-day participation in general education settings.*

Research on the use of technology for students with disabilities has expanded considerably over the last two decades, resulting in an agenda that encompasses a diverse range of innovative instructional and assessment programs. In addition to experimental research, important observational and naturalistic studies have been conducted during this period of time, the general findings of which are a sober reminder of how difficult it is to translate innovation of any kind into practice. Finally, studies of assistive devices, though fewer in number, have uniquely contributed to what now broadly constitutes special education technology research.

This range and depth of research did not exist in the 1970s or the early 1980s. The limited number of studies in special education technology from those years tended to reflect a general interest in the impact of microcomputers on *all* students in public schools. At the time, technologists in both general and special education largely focused on the effectiveness and the efficiency of computer-assisted instruction (CAI). Software programs for general and special education students were commercially developed and were predominantly limited to drill-and-practice programs, tutorials, or simulations (Budoff, Thormann, & Gras, 1984). And like the reports and journal articles in mainstream journals, writings on technology in the special education literature were generally enthusiastic about the potential of the microcomputer (Hasselbring, 1984), a phenomenon that generated prematurely high expectations and subsequent skepticism (Cuban, 1986; Ellis & Sabornie, 1986; Okolo, Bahr, & Rieth, 1993; Woodward, 1993).

Arguably, technology research in special education became more distinctive when researchers began examining ways in which technology could simplify the

diverse if not overly complex roles required of public school special educators. The day-to-day activities of these individuals was (and remains) more than instructional. Special education teachers, particularly resource room teachers, were charged with diagnostic responsibilities (i.e., determining eligibility for special education services), as well as documenting student progress toward the goals enumerated in individualized educational programs, or IEPs. Researchers also began exploring how unique applications of technology could be applied to the needs of "low-incident" populations such as students with hearing and visual impairments, mental retardation, and physical disabilities.

A central force in accelerating the research and development of technology in special education from the early 1980s onward was the U.S. Department of Education's Office of Special Education Programs. Extensive funding in the form of open or "field-initiated" competitions for research on students with disabilities—as well as numerous directed competitions funded by the Technology, Media, and Materials Program—enabled researchers to investigate an array of issues (Hauser & Malouf, 1994), from projected applications of technology available (at the time) only to the military and business to the use of technology for administrative purposes. Since 1986, this program has sponsored over $35 million of research and development designed to advance the quality, availability, and effective use of technology (Okolo, Cavalier, Ferretti, & MacArthur, 1995). To be sure, this level of support for software development and research has dramatically advanced technology research in special education.

## [illegible]t Literature Reviews on Special Education Technology

Previous reviews of the research have used either meta-analytic techniques or broad, thematic approaches to the literature on the use of technology for students with disabilities. More importantly, they have focused almost exclusively on the academic effectiveness of educational technologies. Schmidt, Weinstein, Niemic, and Walberg (1986), while citing a number of problems with the extant CAI research (e.g., anecdotal or poorly written results, use of single-subject as well as group designs), nonetheless conducted a meta-analysis of a subset of the literature. Their meta-analysis, which generally supported CAI as a means of increasing academic performance for students with disabilities, was based on global comparisons of CAI and traditional forms of instruction. McDermid (1989) presented a similar analysis of the literature, while also highlighting the substandard nature of many research reports of the time.

Ellis and Sabornie (1986) offered another method of research synthesis that has continued until today. They organized their synthesis of the technology literature thematically. Specifically, they delineated a series of "promises" that reflected hypotheses or expectations for CAI which were either explicit in individual studies or widely held beliefs about the potential benefits of the use of technology in special education. More recently, Shiah, Mastropieri, and Scruggs (1995) used content areas as a framework for reviewing CAI studies. That is, they examined the impact of CAI on mathematics, spelling, reading, and other subject areas. The findings, while mixed, generally supported the potential of CAI for raising academic achievement. Fitzgerald and Koury (1996) offer a similar review of the literature on students with mild and moderate disabilities.

Although these research syntheses may help illuminate the extent to which CAI is effective, they also reflect three fundamental problems. First, as Okolo et al. (1993) note, many meta-analyses and research syntheses (e.g., McDermid, 1989; Schmidt et al., 1986) offer comparisons that are too global in scope. There is a confounding of medium and instructional principles, one that Clark (1983) describes in a widely cited critique of media research. This problem is apparent in many of the early CAI studies (e.g., McDermott & Watkins, 1983), in which researchers imply that the medium alone can produce significant instructional or cognitive benefits. This issue is compounded further in studies in which the technology incorporates multiple curriculum design variables that are in turn contrasted with traditional instructional methods (e.g., Horton, Lovitt, & Slocum, 1988; Kelly, Gersten, & Carnine, 1990; L. Moore & Carnine, 1989). As Clark argues, it is not the medium but the curriculum design principles embedded in the software that are more likely to contribute to any academic outcomes that favor the use of technology. This confounding has generally not been explored in past research literature syntheses.

A second and more subtle issue involves the underlying hypothesis, seen in most studies, that CAI should lead to cognitive gains superior to those produced by traditional instructional methods. This is particularly apparent in the thematic treatments of the technology literature. Research, particularly when it is conducted under somewhat naturalistic conditions, may lead to nonsignificant findings for a variety of reasons, from the fidelity of implementation to weak research designs. However, other explanations—ones not substantively explored in previous research syntheses—may pertain.

As Okolo et al. (1993) observe, "Because students with disabilities can be expected to learn at slower rates, have longer histories of academic failure, and need more intensive instruction than their non-disabled peers, short-term interventions hardly can be expected to produce significant changes" (p. 4). The expectation, then, of significant changes in academic performance may not be well founded, given that many students with disabilities by definition exhibit profound learning difficulties and that progress over time is highly irregular. Thus, systematically examining the literature for box-score gains may implicitly overestimate the potential effects of CAI for this population of students. Furthermore, such analyses may unintentionally ignore other benefits of CAI for students with disabilities (e.g., improved motivation).

A final problem with most earlier research syntheses and meta-analyses has been the restricted scope of the literature reviewed. As noted earlier, it was not until the 1980s that special educators gradually began investigating technology outside of the traditional CAI framework. Much of the research that has looked at ways in which technology could monitor progress toward IEP goals, assess students to determine eligibility for special education services, or document how technology is used under naturalistic conditions has not been included in other syntheses. Semmel and Lieber's (1986) review is one of the few that discusses the naturalistic uses of microcomputers in special education settings. These other areas of research have led to a body of literature that is richer and more complex than a simple discussion of how microcomputers can be used as teaching machines.

## Organization of the Review

This review of research on the applications of technology in special education presents a historical as well as thematic synthesis of the extant literature. The special nature of special education technology research is that it is directly tied to a series of traditional questions in the field (e.g., how to accurately and reliably determine eligibility for special education services, how to adapt instruction or provide assistive devices to best meet individual needs, how to systematically track progress toward IEP goals over time). Thus, there have been distinct but related themes in research efforts over the last 15 years.

The first section of this article describes research efforts over the last 15 years that have examined the academic impact of technology-based instruction on students with disabilities. Rather than a meta-analysis of CAI or a summary of CAI and its effectiveness by content area, the research will be presented as it evolved historically, that is, from broad comparisons between CAI and traditional instruction to a more focused look at the effects of instructional variables (e.g., feedback, schedules of practice, explicit strategies) embedded in the software. This section will also review research into more comprehensive instructional interventions through videodiscs and multimedia. Much of the research discussed in this section is guided by the effort to adapt software to the unique instructional needs of students with mild disabilities.

The second section offers a summary of the research conducted since the mid-1980s in the area of computer-based assessment. Sophisticated programs, often developed by the same researchers who conducted the cited studies, are used to determine a student's eligibility for special education services and to monitor a student's day-to-day progress toward annual IEP goals. Other innovative assessment programs model student understanding in arithmetic or social competence in the classroom. Technology provides researchers a medium for systematically and reliably analyzing student behavior.

Finally, the third section of this review examines the limited observational and naturalistic research that has been done regarding the use of technology for students with disabilities. Studies conducted over the last 15 years attest to a range of logistical as well as pedagogical constraints. These findings serve as an important counterpoint to the central assumptions that special education researchers tend to make regarding the optimal use of computers in special education settings. Many in this field uncritically believe that research and/or technology developed by professionals should transfer directly to everyday settings. The studies discussed in this section of the review underscore the need for a closer look at issues of professional development if special education technology research is to become a part of common practice.

## Literature Search Procedures

The studies included in this review were located after an extensive search of electronic and print resources. A computerized search was conducted of the Educational Resources Information Center (ERIC) database and the *Psychological Abstracts* and *Dissertation Abstracts International* databases, from 1980 until the present. Key terms such as *technology, computers, disabilities,* and *special education* were used in the searches. Citations from previous literature syntheses

and meta-analyses of applications of technology in education were examined along with those in primary sources. Lastly, a manual search of material published in the major educational research journals between 1980 and the present was conducted, and particular attention was paid to *Journal of Special Education Technology*, *Journal of Educational Computing Research*, *Exceptional Children*, *Journal of Special Education*, and *Journal of Learning Disabilities*. A previous analysis of the literature on uses of technology in special education by Costlow, Lloyd, Tankersley, and Ball (1991) suggested that published research on the topic was minimal prior to 1980 and dramatically increased after 1985.

While a number of these sources, particularly the ERIC database, contained articles on special education technology, a significant number of the articles retrieved are best described as idea pieces, position papers, pilot studies, or project summaries. These reports did not contain primary research in any significant way. Instead, they offered detailed suggestions for how technology might be used for students with disabilities. These articles were excluded from this review, as were many ERIC reports that were later published in professional journals. Many reports on assistive technologies were also excluded because they were primarily technical descriptions of products rather than research reports.

Finally, we infrequently encountered empirical studies that did not fit within the thematic framework of this article. Research on technology use at the university level with preservice students in special education programs, for example, was excluded.

## s of Technology for Instruction

Early syntheses of CAI evaluations (e.g., Kulik, Bangert, & Williams, 1983) suggested that computers were best suited for low-level skills instruction. While remedial and special education literature has documented a variety of effective interventions for skills development such as direct instruction (W. Becker, 1977; Englert, 1984), peer tutoring (Delquadri, Greenwood, Whorton, Carta, & Hall, 1986; L. Fuchs, Fuchs, Bentz, Phillips, & Hamlett, 1994), and cooperative learning (D. Johnson & Johnson, 1986; R. Stevens & Slavin, 1991), these methods have tended to be labor intensive and have required added teacher training. When microcomputers were introduced in the mid-1970s, CAI held the promise of providing intensive, individualized remediation for students with disabilities, while being less demanding of the teacher's time and training.

Thus, many studies conducted throughout the 1980s attempted to determine whether CAI was a complete or stand-alone instructional delivery system, or if some form of explicit teacher guidance, supervision, or direct instruction was also needed. This was seen as a particularly important issue if CAI was to do more than drill students on low-level skills such as math facts or spelling words. Empirical support for computer programs that could successfully tutor students with disabilities in areas ranging from logic to geography or health education was critical, given the range of academic subjects special education teachers were expected to teach, as well as the typically limited content preparation these individuals have in their preservice education (see Cawley, 1994).

Special education researchers were also attracted to technology as a potential way of resolving one of the field's most perplexing logistical and pedagogical dilemmas: truly individualized instruction that addresses a student's specific

deficits. After all, individualized instruction was one of the central purposes of the IEP. In practice, it was not uncommon that, at any one time, a special education teacher working with even a small classroom of students would have to remedy a wide array of academic deficits. In reading, it may be necessary to teach beginning decoding to one student and more generalized, metacognitive instruction for comprehension monitoring to another. This necessity of teaching so many different skills is often a function of scheduling (e.g., agreements between special education and mainstreamed classroom teachers to pull out all students at a particular grade level for reading instruction at one time). Unfortunately, teachers are also often limited in the number of remedial techniques that they use to teach concepts (L. Fuchs, Fuchs, Bishop, & Simmons, 1992; Woodward & Howard, 1994). Naturally, technology-based instruction seemed well suited to the time, intensity, and consistency needed for remedying severe academic deficits (Hasselbring, 1984). To this end, an initial series of studies broadly compared CAI with traditional forms of instruction.

### *CAI and Conventional Instruction*

McDermott and Watkins's (1983) study of commercial CAI math and spelling programs typifies the early comparisons between CAI on microcomputers and traditional textbook instruction. In their year-long study, 205 elementary school students with learning disabilities were taught with CAI spelling, CAI math, or conventional methods. Results on two norm-referenced measures indicated no significant effects for CAI, perhaps due to the overall quality of the software programs. Special education technologists (e.g., Hofmeister, 1984) at the time criticized the low quality of early commercial CAI programs, citing the lack of attention to such important instructional design variables as the careful selection of examples, the quantity and type of feedback, and the use of cumulative review procedures. Special education curriculum designers felt that these variables could positively affect academic outcomes for students with disabilities.

Trifiletti, Firth, and Armstrong's (1984) study was an early attempt to address this concern. These researchers found that when students with mild disabilities used CAI programs following a mastery learning paradigm, they learned twice as much as students who learned through conventional methods such as textbooks and worksheets.

Subsequent studies comparing CAI and traditional instruction have more thoroughly examined the specific instructional design variables used in software programs. In response to guidelines articulated by Hofmeister (1984) and others, Horton et al. (1988), for example, used an experimenter-developed CAI program that contained prompting, feedback, and cumulative review techniques in a high school geography study contrasting technology-based instruction with traditional worksheet methods.

Higgins and Boone (1990) reported successful results for hypermedia study guides in a comparison of three conditions: lecture, lecture and hypertext study guide, and hypertext study guide alone. The hypertext study guide that accompanied the Washington state history text incorporated typical branching methods (e.g., buttons linked to graphic displays, vocabulary terms defined on a separate window). The authors have employed hypermedia as a supplement to reading texts in two other studies (Boone & Higgins, 1993; Higgins & Boone, 1991) in

which traditional norm-referenced measures were used as key dependent measures. In each case, results generally supported the use of hypermedia as an instructional aide.

Although other broad comparisons of CAI and conventional instruction for students with disabilities have been done since the early 1980s (e.g., Lally, 1981; Podell, Tournaki-Rein, & Lin, 1992; Van Laarhoven, 1996; Watkins, 1989), their numbers have diminished in part because of Clark's (1983) critique of media research. In some of the studies (e.g., McDermott & Watkins, 1983), the impact of the media may have been overestimated; hence, Clark's observation that media are only delivery systems pertains. In other studies, in which researchers were more explicitly concerned with instructional design variables, it has also been suggested that the medium (e.g., CAI, hypertext) contributed to outcomes that generally favored technology-based instruction. Consequently, there has been a substantial confounding of the reputed benefits of the media and format or instructional design features that have also varied across experimental and comparison conditions. These problems typically have been overlooked in previous research syntheses on special education technology.

It should be noted, however, that empirical research in assistive technologies offers the most literal support for Clark's (1983) critique. Studies are frequently designed to show how an adaptive device such as a scanning device and a head mounting switch can create opportunities for more substantive interaction between a student with severe physical disabilities and a teacher (Light, 1993). Voice-activated computer systems (C. Brown & Cavalier, 1992), touch-sensitive screens (Battenberg & Merbler, 1989), and voice transcription systems (Wetzel, 1993) have all been used as delivery systems for some kind of enhanced instruction.

### *Instructional Design Variables*

By the mid-1980s, technology researchers in special education began modifying commercial software or developing computer programs for finer-grained research purposes. Dissatisfied with the limited range of software as well as its overall quality, technologists turned to a well articulated body of process-product and instructional design principles which they used in CAI development and research. In many instances, researchers applied principles that were commonly used in highly behavioral, task-analytic approaches to instruction (Engelmann & Carnine, 1982; Gagné, Briggs, & Wager, 1988; J. Moore, 1986; Woodward et al., 1986).

Other researchers approached the design of technology-based instruction from an information processing framework. Explicit techniques for controlled practice and feedback on basic skills were viewed as developing automaticity, something that allowed students to devote more cognitive resources to comprehension or problem solving (Goldman & Pellegrino, 1987; Hasselbring, Goin, & Bransford, 1988; Lesgold & Resnick, 1982).

Research from the mid-1980s through the early 1990s, then, examined the impact of discrete variables such as feedback, massed and distributed practice, and explicit cognitive strategies. In a wider sense, motivation was also examined because of its direct relation to drill-and-practice programs. CAI programs allowed researchers to explore these variables, often under highly controlled con-

ditions in which students in the experimental and comparison conditions used modified versions of the same CAI program. Special education technology researchers (e.g., Carnine, 1989) noted that in instances when the medium did vary, it was the specific instructional design principles rather than the medium (i.e., not the CAI or the textbook) that contributed to significant differences in outcomes. These studies clearly attempted to address Clark's (1983) observations on media as a confounding variable in instructional technology research.

*Feedback*

Non-technology-based research in special education has long pointed to various forms of feedback as a critical instructional design variable for students with disabilities. Correlational (Englert, 1984) and observational (Rieth & Frick, 1983) research during the 1980s suggested that this was an effective practice for enhancing student understanding, at least for basic skills. Feedback in these contexts has connoted either redundant information (e.g., visual prompts, verbal cuing) or immediate corrective feedback (e.g., "correct/incorrect," "right/try again"). Further research syntheses (e.g., Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Lysakowski & Walberg, 1982) supported the use of even more detailed forms of feedback. For example, instead of merely telling students the correct answer, these researchers argued that strategic feedback—briefly reviewing the steps or strategies for answering a question or completing an algorithm—was an even more effective way of reducing errors and helping students master skills.

*Feedback as redundant information.* Torgesen and his colleagues (Torgesen, Waters, Cohen, & Torgesen, 1988) conducted a series of studies on the effects of speech synthesis as a form of feedback. They were particularly interested in the different informational attributes of microcomputers (i.e., graphics, sound, and text) and their effects on the beginning decoding process in reading.

Torgesen et al. (1988) found that students who were taught decoding with three different computer presentations—visual only (pictorial representation of the word and the word itself), audiovisual (pictorial representation, synthesized pronunciation of the word, and the word itself), and audio only (synthesized pronunciation of the word and the word itself)—showed comparable improvements in levels of speed and accuracy, at least when contrasted with a no-treatment condition. Moreover, the number of sessions required to achieve word mastery was similar. Other reading studies (e.g., Jones, Torgesen, & Sexton, 1987; Wise & Olson, 1994) generally support the view that synthesized speech can help students learn how to segment words.

The effectiveness of speech synthesis is less clear when students are allowed to employ it selectively. In Farmer, Klein, and Bryson's (1992) study, students with learning disabilities could highlight words they did not know, and a speech synthesis device would pronounce the words for them. When measures of comprehension and word recognition indicated no significant differences, the authors suggested that poor readers may tend to skip over words they do not know in text and thus be less likely to choose added information even if it might enhance understanding. Van Daal and van der Leij (1992) also found that speech synthesis alone had no significant effect on learning to spell. Levert (1988) reported a similar lack of effects for speech synthesis when used in this manner.

These studies have implications for hypertext and multimedia. While added

sources of information (e.g., graphics, definitions, background text on separate windows) through dynamic links may be *available* to students, there is no reason to believe that these options will be employed consistently, if at all. How students have actually used hypermedia in recent reading research (Higgins & Boone, 1990, 1991) has not been documented.

*Simple feedback.* Using the computer for simple corrective feedback has also produced mixed results. For low-level skills such as memorizing spelling words, research has shown that immediate "correct/incorrect" feedback is more effective than conventional methods whereby students receive delayed feedback either at the end of the lesson or the next day (MacArthur, Haynes, Harris, & Owings, 1990). CAI also led to higher on-task rates or higher rates of student engagement.

Other studies (e.g., Howell, Sidorenko, & Jurica, 1987; Lin, Podell, & Rein, 1991) contradict this finding, suggesting that for simple declarative knowledge tasks such as memorizing vocabulary words or math facts, human tutors are more sensitive to individual needs. In their CAI studies, tutors were able to offer more precise, task-specific feedback and were capable of maintaining higher levels of engagement during drill-and-practice sessions. Furthermore, as Lin et al. noted, while computer use tended to increase the rate at which students answered, the students were more accurate when doing paper-and-pencil activities. Based on this finding, Lin et al. recommended a gradual progression from paper-and-pencil practice to computer drill.

*Complex feedback.* The extent to which computers can be an effective mechanism for more complex forms of feedback is equally mixed and appears to be contingent upon the nature of the task. For simple tasks, attempts to increase efficacy and self-esteem through positive attributions (e.g., "You are really trying hard," "You really know these") may be undercut by instruction that is initially or even progressively tailored to a student's level of competence.

Okolo's (1992) comparison study of a CAI math fact program that was modified to provide either attributional or simple feedback, students in both conditions showed progressive declines in the way they attributed increased success on math facts as a function of ability. Okolo proposed that the controlled nature of the practice led students to attribute success to easy problems rather than ability.

Collins, Carnine, and Gersten (1987), on the other hand, found complex or strategic feedback to be highly effective in teaching secondary students with learning disabilities how to draw conclusions from two statements of evidence and how to determine whether a three-statement syllogism was logically correct or incorrect. As in the Okolo (1992) study, the researchers modified the type of feedback while keeping all other instructional features the same. Elaborate feedback for errors (i.e., feedback that gave the correct answer and reminded of the reason or strategy for determining that answer) was much more effective than simple right/wrong feedback. For a challenging if not artificial task like syllogistic logic, complex feedback may be an effective variable for increasing student achievement.

### *Massed and Distributed Practice*

Another instructional design variable directly related to systematic basic skills practice has to do with the quantity and distribution of new information. As cognitive psychologists and educators (Anderson, 1983; Pellegrino & Goldman,

1987) have argued, automaticity in basic skills allows limited cognitive resources to be devoted to other, more complex tasks. Behavioral educators (W. Becker, 1986; Engelmann & Carnine, 1982; Kameenui & Simmons, 1990), using the language of mastery learning, make similar claims based on the importance of strong stimulus-response associations. Two controlled CAI studies, one from each theoretical perspective, suggest that attention to massed and distributed practice variables does have a positive effect on the acquisition of declarative knowledge or facts.

Hasselbring et al.'s (1988) CAI addition fact program builds on existing declarative knowledge by initially pretesting the student on the range of facts. Once the unknown pool of facts is established, the program gradually introduces more difficult facts as determined by the size of the addends. The amount of practice on new facts is carefully controlled—no more than two new facts and their reversals at any one time. Finally, practice is systematic, with new or target facts interspersed with known facts. Research using commercial software in which these features are missing suggests that students are more likely to retain alternative, inefficient strategies such as counting rather than direct retrieval of math facts (Bahr & Rieth, 1989).

G. Johnson, Gersten, and Carnine (1987) achieved similar results when comparing an experimenter-designed CAI program that controlled massed and distributed practice with a commercial CAI program that introduced new vocabulary in groups of 25 words at a time. The experimenter-designed program, like Hasselbring et al.'s, pretests students for their vocabulary knowledge and then teaches only unknown words. Practice sets are restricted to seven words, and students are required to master each word before it is removed from the set. New words are added progressively, and cumulative review occurs for every 10 words. Similar studies involving researcher-developed CAI programs in which the material is systematically reviewed over time have been conducted in social studies (Gleason, Carnine, & Vala, 1991) and spelling (K. Stevens, Blackhurst, & Slator, 1991). Results strongly support the use of both massed and distributed practice.

### *Explicit Strategies*

When students engage in tasks beyond the rote, drill-and-practice level, it is essential that they utilize some form of metacognitive planning, evaluation, and monitoring. Unfortunately, these are distinct areas of weakness for students with learning disabilities (Pressley, Goodchild, Fleet, Zajchowski, & Evans, 1989; Swanson, 1989; Wong, 1993). A general inability to mediate instruction has led special educators to advocate a variety of strategy instruction techniques, from broadly applicable metacognitive strategies to ones that are highly content specific. Despite the diverse interpretations of strategy instruction in the literature, special educators (deBettencourt, 1987; Ellis, 1993; Harris & Pressley, 1991) generally agree that strategies need to be taught explicitly and that successful instruction requires focused practice and long-term follow-up. Explicit strategy instruction has characterized a portion of the special education technology research, and like the broader debate in the field, the studies cover the range of strategy orientations from highly task-specific to more generalized approaches.

Carnine and his colleagues (Gleason, 1985; Gleason, Carnine, & Boriero, 1990; Grossen & Carnine, 1990) examined the role of task-specific strategies in a series

of studies on math and logic CAI tutorials. Secondary students with learning disabilities successfully learned how to solve traditional math problems through CAI alone. The computer program presented a keyword strategy for analyzing word problems (e.g., *each* and *every* mean to multiply or divide). Equally significant results were achieved in syllogistic reasoning by having students draw logical relationships using a Euler diagram with paper and pencil in addition to learning from a CAI program (Grossen & Carnine, 1990). Researchers also measured how students applied their rule-based understanding to a range of transfer problems. For the most part, students were able to successfully work exercises that were closely related in style and content to those taught on the CAI programs.

According to Carnine (1989), these studies demonstrated that students could learn complex material from CAI tutorial programs if specific instructional design principles were employed. Even though the students in these studies had marginal success on transfer problems, the claim was nonetheless important if CAI was to be used for more than systematic drill and practice.

Woodward and his colleagues (Hollingsworth & Woodward, 1993; Woodward, Carnine, & Gersten, 1988) examined the extent to which more generalized metacognitive strategies for monitoring and planning could be linked to health education using a computer simulation. The complexity of the simulation required that the teacher provide explicit strategies for how to apply background knowledge as well as manage multiple variables during each computer game. Researchers found that students were able to apply their problem-solving strategies to exercises (videotape vignettes in one case) that were closely related to what they were taught during the interventions.

Explicit strategy instruction for reading (Graham & Harris, 1989; Graham & Johnson, 1989) and writing (Englert, Raphael, & Anderson, 1992) requires even broader, more flexible strategies than those described above. In reading, particularly in content area materials, students are taught a variety of comprehension monitoring strategies that include note taking, generating and/or answering text-embedded questions, and using glossaries and dictionaries. MacArthur and Haynes (1995) designed a software system that contained all of these features and others (e.g., speech synthesis). Separate windows contained text outlines, pictures, and a miniature word processor for note taking. They found that students rated the highlighting of main ideas and questions linked to the text as the most helpful features of the program, while speech synthesis was viewed as only moderately helpful. Research on this system to date has been limited, and their work does not fully reflect the program's possible integration with teacher-directed instruction in these reading strategies.

On the other hand, explicit strategies for writing have been more clearly integrated into the overall instructional process, as demonstrated by recent studies (Graham & MacArthur, 1988; MacArthur & Graham, 1987). Based on a six-step metacognitive technique for improving clarity and cohesiveness in essays using a word processor, researchers found that word processing can be an effective vehicle for improving writing. Furthermore, because many students with learning disabilities have compounded problems in writing due to poor handwriting, word processors do more than facilitate writing. They afford drafts and a final version of an essay which are considerably more legible than what students typically produce.

### *Motivation*

Although students with learning disabilities are generally acknowledged to have significant deficits in basic skills, special educators (Deci & Chandler, 1986; Okolo, 1992) also note that motivation is a key factor that influences their performance. Ensuring that students will benefit from the discrete instructional design variables mentioned above and attain high levels of proficiency in a CAI environment, then, is contingent on their active engagement. This issue becomes even more important in computer lab settings, where it is difficult for a teacher to successfully monitor individual students (Rieth, Bahr, Okolo, Polsgrove, Eckert, 1988). Thus, there have been a series of studies exploring the motivational effects of arcade-like games on the acquisition of math facts and vocabulary words.

Christensen and Gerber (1990) compared a popular math CAI drill-and-practice arcade program with an experimenter-developed, non-arcade program containing addition math facts and, like its commercial counterpart, simple corrective feedback. While all students showed considerable gains over the course of the study, those students who used the non-arcade program showed the greatest gains. Researchers also found that students in the experimental group practiced significantly more problems than the arcade group.

These results are consistent with other studies (Axelrod, McGregor, Sherman, & Hamlet, 1987; Chiang, 1986) which have indicated that arcade games create extraneous distractions and that potential increases in learning come at the expense of entertaining learning environments. Bahr and Rieth (1989), in a study of multiplication drill-and-practice arcade games, also found that games had little effect, in part because they were not incorporated into regular classroom instruction.

Only Malouf's (1988) study of vocabulary acquisition indicated that students who played a "space invaders" program, where they matched prefixes with root words, showed higher levels of motivation for the arcade condition. However, motivation was measured on tasks that immediately followed the intervention, and the researchers acknowledged that the extended effects of the program were not documented. Furthermore, they reported equivalent increases in academic performance for all students in the study.

These studies suggest that arcade games compete for time and attention in the context of drill and practice. Under carefully supervised conditions, arcade games seem to detract from the high amounts of practice required of students with disabilities if they are to master target skills. Researchers also contend that relatively poor performance on game software may be a function of selective attention deficits (Semmel & Lieber, 1986). Consequently, students with learning disabilities are less capable than their nondisabled peers of focusing on the drill features of the program.

### *Summary*

Over a decade of research that began in the mid-1980s reflects a concentrated effort to validate the effects of different instructional design variables on CAI. This is particularly apparent in studies in which students used virtually identical versions of the same software program but for the presence or absence of one variable. This phase of technology-based instructional research fully reflects

Clark's (1983) early criticisms of media research.

The focus on instructional design variables is apparent when one examines the nature of the instructional tasks as well as the context in which they are taught. In many instances, highly unusual tasks (e.g., syllogistic logic) were used as a background for examining feedback and explicit strategies rather than the kind of instruction in conditional reasoning that would more closely approximate how humans make logical inferences (see Johnson-Laird, 1983; Kuhn, 1991). In other studies, little is said about the relationship of the specific skills taught through CAI to a broader curriculum. The speech synthesis studies (Torgesen et al., 1988) focus almost exclusively on the decoding process, with little discussion as to how this kind of practice on the computer is orchestrated with other elements of reading instruction. One can only infer from these studies that special educators would somehow use CAI to teach the discrete and labor-intensive aspect of a curriculum (e.g., word segmentation in decoding, spelling, math facts, vocabulary words) and then link these computer-based activities to more traditional forms of instruction. As we will discuss later, this connection between computer and noncomputer instruction is difficult for most special education teachers.

Finally, it became apparent in many of the instructional design studies, particularly as researchers examined more complex variables (e.g., explicit strategies), that CAI alone was insufficient as a teaching medium. The simulation research (Hollingsworth & Woodward, 1993; Woodward et al., 1988), for example, placed considerable demands on the teacher. In these studies, teachers departed significantly from the traditional curriculum in the organization of and emphasis on concepts and in the way in which the information was linked to the simulation. These studies also required active involvement on the part of teachers in and away from lab settings. As a response to these concerns and the appearance of more robust technologies such as videodiscs, many special education technologists looked to more comprehensive ways of embedding technology in day-to-day instruction.

## *Comprehensive Interventions*

A distinct strand of research emerged in the late 1980s and continues through the present. Researchers, dissatisfied with the limited storage and graphic capacities of microcomputers, began turning to videodiscs and multimedia tools as ways of more fully integrating technology into content area instruction. Videodiscs offer rich graphic and storage capabilities—approximately one half hour of continuous video or 54,000 still frames per side—and provide programs that can be used with an entire group of students in a classroom. Multimedia tools enable students to interact with computers in fundamentally new ways. At the very least, students may not need to use technology in a passive, one-on-one basis, as they have in the past (Kozma, 1991). These features alone ease the logistical and supervisory problems commonly associated with computer labs.

### *Videodisc Instruction in Core Concepts*

In the late 1980s, a small group of research and curriculum developers (Hofmeister, Engelmann, & Carnine, 1989; Hofmeister & Thorkildsen, 1989) created a series of commercial videodisc programs in the areas of math and science known as the Core Concepts programs (Systems Impact, 1985, 1987a,

1987b). The developers encoded into their programs those instructional design variables investigated in previous CAI research (e.g., simple and strategic feedback, massed and distributed practice, explicit strategies) as well as an array of additional behavioral instructional design variables (e.g., hierarchical task analysis of concepts, a careful selection of examples for teaching a concept, graphical cues that highlighted relevant properties of the stimulus). This resulted in complete instructional programs in traditional secondary topics in mathematics (e.g., fractions, decimals, ratios, algebraic equations), earth science, and chemistry.

Experimental research on these videodisc programs with secondary students with learning disabilities generally supported the packaging of instructional design features in the programs. Manufacturing costs, among other things, did not permit researchers to modify the videodisc programs so that a single variable could be studied. Thus, the studies on students with disabilities typically involved media contrasts (e.g., videodisc versus textbook instruction) as well as systematic variations of instructional design variables. Thus, in studies of secondary and adult students with learning disabilities (Kelly et al., 1990; Kitz & Thorpe, 1992; L. Moore & Carnine, 1989) videodisc programs were compared to traditional texts that were often modified to provide additional computation or word problems. Results on dependent measures, ones that were closely aligned to the videodisc curricula, generally supported the instructional design features of the various programs.

Taken as a whole, these programs represented the culmination of almost two decades of work in developing highly prescriptive print and computer-based curricula. Developers directed not only the content of the courseware, but the sequence of topics and pedagogical strategies (Venezky, 1992). Efforts that began in the Direct Instruction Model in Project Follow Through (W. Becker, 1977) were finally distilled in a series of videodisc programs. Moreover, these highly detailed, step-by-step approaches to skill development epitomized traditional instructional methods in remedial and special education.

*Anchored Instruction*

In stark contrast to the Core Concepts approach, more recent work by the Cognition and Technology Group at Vanderbilt University (CTGV, 1990, 1993a, 1993b) reflects a generally constructivist orientation to learning. Rather than employing technology as a means of distilling or packaging teacher-directed instruction, CTGV efforts have been directed toward embellishing instruction through media tools. A library of computer-based images or brief video clips, for example, may be used to enhance story comprehension or assist primary grade children in developing their own stories (Hasselbring, Goin, & Wissick, 1989). Other uses of media, including rich videodisc simulations or video segments from popular movies, serve as starting points for group discussions and problem solving (Alcantra, 1996; Sherwood, Kinzer, Hasselbring, & Bransford, 1987). Students are encouraged to take an active role in acquiring and analyzing data. By using real-world settings and ill-defined problems, these researchers have attempted to anchor academic exercises in a more contextualized world, one closer to the arena in which students and adults actually solve problems. This perspective is grounded in Vygotsky's (1978) writings and, more recently, Bransford's (Bransford, Sherwood, Vye, & Rieser, 1986; Bransford & Stein, 1984) work in

problem solving.

Bransford, Sherwood, Hasselbring, Kinzer, and Williams (1990) and Hasselbring, Bottge, and Goin (1992) claim that too much of traditional teaching, particularly in special education, has been fragmented instruction on basic skills. They suggest that the students' knowledge, even if mastered, remains inert and hence underused when it is actually needed. This perspective may explain the limited results of earlier CAI studies of instructional variables (Gleason, 1985; Gleason et al., 1990; Grossen & Carnine, 1990).

Bottge and Hasselbring (1993) demonstrated this point in their study of mathematical problem solving. Remedial students and those with learning disabilities first learned fractions and ratios through the Core Concepts programs just described. Classroom discussions, anchored instruction (e.g., real-world problems presented through video vignettes), and general problem-solving techniques (e.g., breaking down the problems into manageable units of information, posing different solution strategies, and asking *what if?* questions) were shown to be superior to techniques whereby students worked problems by following more structured, rule-governed procedures for identifying extraneous information and keywords. This latter method was explicitly taught in the Core Concepts programs.

More recent work at the secondary level with anchored instruction has involved the use of multimedia and productivity tools as complements to the overall instructional process. Social studies researchers (Ferretti & Okolo, 1996; Kinzer, Gabella, & Rieth, 1994; Okolo & Ferretti, in press) have stressed the development of argumentation and reasoning in the context of historical events. Students use a range of tools to develop multimedia programs based on a theme or perspective. Woodward and Baxter (1997) have used commonly available tool software—spreadsheets, in particular—as vehicles for modeling everyday problems. Teachers employ the spreadsheets as one way of presenting mathematical concepts (e.g., proportions, number patterns), and students gather data on everyday problems and use integrated programs to model problems mathematically and write brief summaries and recommendations.

## Technology-Based Assessment

Past syntheses of technology research in special education have rarely, if ever, reviewed computer-based assessment studies. This is likely due to both a more traditional focus on instructional uses of technology and the recency of the assessment research. Nonetheless, special education teachers have role responsibilities that go beyond teaching. They must work with general education teachers and school psychologists to conduct prereferral observations of students at risk for special education. They are also required to make eligibility decisions and document each special education student's progress toward annual IEP goals. Technology has come to be seen as a vehicle for orchestrating higher-quality assessment and reducing the amount of time humans manage the assessment process (Greenwood & Rieth, 1994).

Research over the last decade in computer-based assessment has generally documented how well different technologies can simulate or even augment human assessment, as well as the extent to which these tools are cost effective, in terms of replacing the time-consuming and tedious work normally done by hand.

What is striking about the most prominent strands of this research has been the interplay between software development and research. Frequently, the same researchers have prototyped, evaluated, refined, and researched their assessment systems, only to modify the programs further by adding new features. Another distinctive feature of this development and research is the use of commercial expert systems to aid in the decision-making process.

### *Classroom Observational Systems*

Greenwood and his colleagues (Carta & Greenwood, 1985; Greenwood, Carta, & Atwater, 1991; Greenwood, Carta, Kamps, Terry, & Delquadri, 1994) have used technology to address the problem of prereferral observations and consultations for students at risk for (or currently enrolled in) special education. Through several iterations and field tests, these researchers have developed a highly sophisticated computer program that can be used to document student behavior, teacher behavior, and the instructional features of the classroom environment or ecology. Trained observers make low-inference observations (e.g., the student is reading aloud, the teacher is at the front of the room teaching, the subject is social studies) and use a laptop computer to enter their data. After the observation, professionals (e.g., special educators, teachers, school psychologists) can examine a range of behaviors in isolation or in context of other behaviors using any one of the program's many data display features. Greenwood et al.'s (1991) program also graphically portrays changes in behavior over time, perhaps as a function of an intervention. A nationwide survey formed the basis for the behavioral categories, and the researchers have progressively refined the interface in order to reduce taxonomic complexity (Greenwood et al., 1994).

### *Computer-Based Diagnosis*

Professionals have found decisions regarding eligibility for special education services as well as compliance with district, state, and federal guidelines problematic both because of the complexities and shifts in laws and because of the considerable variations in training for individuals involved in this process. Hofmeister and others (Geldern, Ferra, Parry, & Rude, 1991; Hofmeister, 1986; Hofmeister & Ferrara, 1986; Parry & Hofmeister, 1986) have developed a series of expert system programs that attempt to standardize procedures for determining whether or not a student is eligible for special education services.

Early programs focused on simple eligibility issues (e.g., Was the student sufficiently below grade level in a subject matter?, Did the student have an IQ in the normal range?). Validity studies, the kind that have characterized basic expert system development and research (Hayes-Roth, Waterman, & Lenat, 1983; Wenger, 1987), contrasted human experts with computer programs. More recent programs such as SMH.PAL (Hofmeister et al., 1994) carefully aid the user in identifying important target behaviors and assist in program interventions based on the needs of the student and the teacher's level of sophistication (i.e., the likelihood that the teacher will be able to implement the intervention program). SMH.PAL queries the user and then selects appropriate, research-based methods for changing targeted behaviors. These researchers have also refined earlier expert system programs and added training components as a way of improving field practice (Prater & Ferrara, 1990).

The development of expert systems to determine eligibility satisfies three assessment concerns. First, expert systems offer the potential benefits associated with all expert systems: distributed intelligence or expertise on carefully defined topics. In special education, expert systems can bring a higher level of consistency to the decision-making process. Second, because of this consistency, they offer a way to train users, preservice special educators, and school psychologists. Finally, they make explicit the decision rules and judgments associated with this critical phase of the IEP process (Hofmeister & Ferrara, 1986; Visonhaler, Stewart, Price, & Hall, 1993).

Videodiscs have also played an important role in advanced assessment systems. Irvin and Walker (1993, 1994) developed a system that uses a complex array of technology to assess a student's social skills (e.g., following a teacher's directions, dealing with teasing and provocation). Students enter responses to video vignettes using a touch-sensitive screen. The responses are then analyzed using a microcomputer, and further scenes are accessed from a videodisc player. The program reflects a computerized attempt to encode over two decades of instrument development and research on students with behavior disorders. Multiple measures are used in this video-based system to determine the extent and nature of social competence. Smaller-scale work involving videodiscs for assessment has also been done on students with hearing impairments (Bullis, Reiman, Davis, & Thorkildsen, 1994; Loeding & Crittenden, 1994).

### *Ongoing Assessment*

Through rapid developments in hardware and software, particularly expert systems, special education technologists have also developed ongoing assessment systems that track student progress on a daily basis. The more recent systems have attempted to model student understanding, a long-standing concern of artificial intelligence research in education (Wenger, 1987).

*Curriculum-based measurement.* Researchers have used computers as a means of frequently assessing skills and transforming data into a detailed picture of student progress. Curriculum-based measurement (CBM; Deno, 1985; L. Fuchs, Fuchs, & Hamlett, 1993) offers a dramatic alternative to traditional conceptions of instructional technology in special education. Rather than encode instructional design variables into CAI or videodisc programs, CBM attempts to modify day-to-day instruction based on the results of systematic assessment procedures. Teachers administer skills tests or probes, ones that sample student performance from a domain of items reflecting the student's academic program for the year, on a frequent basis. CBM computer programs present these tests on the computer (or print them on paper), analyze the results, depict progress graphically, and advise teachers on how and when to modify instruction to meet individual needs (L. Fuchs et al., 1993).

CBM is based on a task-analytic, behavior model of learning. Computer displays present an upward sloping growth line that projects the course of student progress on probes over time. If the computer detects a plateau or a significant trend that departs from this line of progress, the program alerts the teacher and, in more recent versions, suggests instructional remedies.

Current computerized versions of CBM reflect a history of effort by a select group of special education researchers who have generally been dissatisfied with

traditional diagnostic testing for placement in special education, as well as the tendency to continue current instruction regardless of the student's ongoing level of success (Deno, 1990; L. Fuchs & Fuchs, 1984, 1986). In terms of instructional interventions, CBM researchers have argued that because a student's academic history involves so much failure, teachers should be cautious in using one approach or program, even if it is empirically validated. Again, this view is in marked contrast to the CAI and videodisc technology efforts described earlier in this article.

Computer-based versions of CBM were developed because attempts at encouraging teachers to use some form of frequent, systematic measurement were deemed too labor intensive (Wesson, Fuchs, Tindal, Mirkin, & Deno, 1986). The earliest computer versions of CBM simply stored, graphed, and analyzed data that had been entered by teachers after formative measures had been prepared, administered, and scored. Even though research on these systems (L. S. Fuchs, Fuchs, Hamlett, & Hasselbring, 1987) suggested that there was little to no savings in time over doing this work by hand, teachers generally preferred the computer version of CBM. The enhanced versions of these CBM systems have virtually eliminated any teacher administration or scoring of student performance data. Students take the tests at the computer (L. Fuchs, Hamlett, Fuchs, Stecker, & Ferguson, 1987), and the program performs the analyses automatically.

Even more recent versions of computerized CBM have added detailed skills analyses and instructional recommendations for teachers. This was done largely because teachers were still unable to translate frequent assessment results into effective instructional programs (L. Fuchs et al., 1993). In current programs, skill performance in a domain (e.g., math facts, concepts, procedures) is broken down and rated across five categories from mastered to not attempted. Each probe updates a student's profile and adjusts the rating (e.g., improvement in borrowing may change from partially mastered to probably mastered) (L. Fuchs, Fuchs, & Hamlett, 1989; L. Fuchs, Fuchs, Hamlett, & Stecker, 1990).

Expert systems have enabled CBM researchers (L. Fuchs, Fuchs, Hamlett, & Ferguson, 1992; L. Fuchs, Fuchs, Hamlett, & Stecker, 1991) to specify in detail procedures for instructional remediation. Previous research (L. Fuchs, Fuchs, Bishop, & Simmons, 1992) indicated that teachers generally reteach skills using the same instructional method and are unable to present content using different methods, ones that may most benefit the individual student. Thus, expert system programs in reading, math, and spelling offered teachers detailed prescriptions. Academic gains, at least as measured by CBM probes, supported the computerized prescriptions in most academic areas (see L. Fuchs et al., 1993).

The most recent use of computerized CBM is to monitor entire group performance, with close attention to the lowest 25th percentile group. This form of CBM was devised to manage whole-class instruction, particularly in mainstreamed settings. The CBM program suggests a range of instructional remediation strategies from CAI to peer tutoring for specific skill development (L. Fuchs et al., 1993).

*Modeling student understanding*. In contrast to the CBM approach, other researchers working in the area of computer-based assessment have developed interactive programs using a cognitive framework. Rather than survey and track competence on a range of skills, these programs systematically probe more deeply

into one domain. They developed around the assumption that students often exhibit persistent errors because of subtle misconceptions and that progress through a curriculum does not follow a linear pattern.

Gerber, Semmel, and Semmel's (1994) DynaMath program, which is rooted in dynamic assessment techniques, probes students through a graduated series of prompts. The program audibly alerts the student to discrete errors, graphically noting the position of the error. At the highest level of prompting, the solution steps in a procedure or subprocedure are modeled in an animated sequence. Over time, student responses are profiled in a database, which in turn affects the generation of new problems. Case study research suggests that the program carefully controls for difficulty, at least as it is measured by procedural complexity.

Woodward and Howard's (1994) TORUS program follows a more traditional model based on the artificial intelligence research of J. Brown and Burton (1978) and Van Lehn (1990). While TORUS emulates many of J. Brown and Burton's Buggy system (e.g., student answers are compared to computer analyses of missed problems, a database of errors or bugs is accessed to determine diagnoses), the core of the program is based on a commercial expert system. As is the case in other uses of expert systems in special education, developers are able to modify and tailor their system to empirical conditions (e.g., the bugs as they are documented through human analyses) and the needs of teachers (e.g., reports that contain certain kinds of information). Field research (Woodward, 1992) indicates that TORUS reliably detects misconceptions and identifies difficulties undetected by other computer-based diagnostic programs such as CBM programs.

## Naturalistic Research

How actual technology use corresponds with researchers' working visions of computer use in classrooms yields important if not sober reminders of the gap between innovation and day-to-day practice. H. Becker's (1983, 1986; H. Becker & Sterling, 1987) national survey data throughout the 1980s offered some insight into the ways technology was used in special education. Moreover, it provided an impetus for looking further at how schools were acquiring and organizing the use of microcomputers.

A large-scale study (Christensen & Cosden, 1986; Cosden, Gerber, Goldman, Semmel, & Semmel, 1986; Cosden, Gerber, Semmel, Goldman, & Semmel, 1987; Cosden & Lieber, 1986) of elementary school students with mild disabilities, conducted in 52 southern California districts using stratified random sampling, suggested that students in pull-out or special day classes were assigned to work on computers in their special education classrooms rather than in mainstreamed settings or school labs. Unlike mainstreamed students with learning disabilities, these students tended to work on computers by themselves rather than in small groups. This phenomenon was largely due to the high ratio of students to computers in the more restricted settings. However, students in these more restricted settings generally had less time on computers than students with learning disabilities in mainstreamed settings. Regardless of setting, students with mild disabilities tended to spend much more time working on drill-and-practice programs than their nondisabled peers. The data also suggested a discontinuity between the CAI software and the content being studied away from the computers (Cosden &

Abernathy, 1990). These patterns persisted over time in a longitudinal study conducted with many of the same schools that participated in the original study (Cosden & Semmel, 1987).

Students with disabilities exhibited consistently high engagement rates. This observation has been reported in several other studies of microcomputer use for students with mild disabilities (MacArthur, Haynes, & Malouf, 1986; Sapona, Lloyd, & Wissick, 1986). Apparently high levels of engagement, at least as has been determined through low-inference observational systems, occurred in spite of the fact that special education teachers tended to have relatively few direct contacts with students while they worked on computers. While this may have had a marginal effect on levels of engagement, error rates as well as the overall quality of completed activities could have been adversely affected by the limited student contact (Cosden & Semmel, 1987).

Research at the secondary level (Rieth et al., 1988; Rieth, Bahr, Polsgrove, Okolo, & Eckert, 1987) reported similar findings. Rieth and his colleagues found relatively low levels of computer use for students with learning disabilities, and when the computer was used, it was largely for drill and practice in math and spelling. Levels of teacher feedback in these observations were also relatively low. Like the elementary school research (Cosden et al., 1987), these data suggest that the computer may be replacing important teacher-directed instruction.

A survey of special educators (Cosden, 1988) revealed that teachers generally felt that students showed increases in basic skills when using commercial programs. This was true even though they had a difficult time judging that students benefitted the most from these activities. This was largely due to their inability to measure the benefits of CAI and their unfamiliarity with relatively new software programs. It should be noted that teachers also expressed frustration with the quality of available software. And while these teachers rated drill and practice to be effective, they also felt that microcomputer use had a considerable and positive effect on motivation and self-esteem.

Neuman (1991) offered a deeper, if not more disquieting, analysis of how students interact with computers in her qualitative account of computer use at a middle school for students with learning disabilities. Over the course of 6 months, Neuman found that students faced an alarming number of barriers when using commercial software programs, from understanding teacher directions for gaining access to courseware to an inability to read information on the computer displays. In fact, students generally disliked reading from the screen and deduced other ways to accomplish what the program required. It was common for students to approach even the most routine drill-and-practice programs in a competitive fashion, a disposition presumably based on their wider experience with computer games. Students challenged others, gave themselves pep talks, introduced artificial time constraints, and figured out ways to reset programs to avoid penalties that would have resulted in lower scores.

Neuman's research highlights the erratic ways in which students with learning disabilities employ metacognition. As has been noted in other qualitative research (Rueda & Mehan, 1986), students with disabilities appear more than capable of working around barriers or natural constraints and, at times, effectively subverting the direct intentions of a curriculum.

In another study (MacArthur & Malouf, 1991) of computer use, the gap

between what special education technology researchers advocate and what teachers do (and believe) in their day-to-day practice was equally revealing. In three case studies, these researchers found that teachers used computers largely for motivation and to improve self-esteem and not necessarily to raise academic achievement. Because these teachers generally used an extensive amount of individualized, independent seatwork in their everyday classroom routines, it was natural for them to fit computer use into an individualized format. But teachers also were casual in the way they assigned drill-and-practice activities on the computer, leaving students, at times, to work on inappropriate content. In part, this was due to the logistical problems of reviewing software. Teachers consistently found it much easier to skim a workbook and determine if the skills were appropriate than to review software programs. Thus, teachers rationalized the value of computer work largely on the basis of its potential benefits for motivation and self-esteem.

Even with specific technology training, teachers still exhibit uneven patterns of use. Bahr, Kinzer, and Rieth (1991) found in a reading comprehension study that even after explicit training, teachers found it difficult to integrate prequestion strategies for passages displayed on a computer screen. Woodward's (1993) analysis of the Core Concepts videodisc research indicated that teachers varied widely in how they used the programs once the formal studies ended. In one naturalistic study (Woodward & Gersten, 1992), eight teachers responded enthusiastically to the program, but only one requested to use it the following year. In other studies (Kelly et al., 1990; Woodward, 1994), either teachers were erratic in the way they used the program on a day-to-day basis, or they were interested only in using brief segments of the program intermittently.

## Concluding Remarks

Research presented in this review attempts to go beyond the traditional perspective of past syntheses of research on special education technology. Rather than focus predominantly on the effects of CAI on learning, this review has attempted to capture other recent developments in areas such as assessment and naturalistic research. As these two other strands suggest, there is no single theoretical framework or raison d'être for special education technology research. Rather, the research is best seen as systematic attempts to apply technology to traditional special education problems such as identification, ongoing assessment, and individualized instruction.

To be sure, one of the most obvious influences on this research, at least from a historical perspective, is the role of increasingly sophisticated and cost-effective hardware and software. The appearance of expert systems, multimedia software and hardware, and a range of other devices previously unseen outside of laboratories and the military has dramatically broadened special education technology research.

However, it should also be noted that even though the technologies have evolved, the guiding theoretical frameworks, particularly learning theories, have often remained constant. Some researchers (e.g., Carnine, 1989; L. Fuchs et al., 1994; L. Fuchs et al., 1993; L. Fuchs, Hamlett, et al., 1987) have studied the use of a range of technologies all the while guided by the same behavioral approaches to instruction. Skill-based instruction originally presented through CAI, for ex-

ample, appeared on videodisc and as a feature of expert system analyses of student performance.

In contrast, more recent efforts to embed technology as a tool in multimedia and constructivist environments (e.g., CTGV, 1993a; Dauite & Morse, 1994; Kinzer et al., 1994; Okolo & Ferretti, in press) clearly suggest a shift to more cognitive theories of learning. While instructional adaptations are made for the special education learner, they may be a function more of a teacher's pedagogical techniques and materials than of the technology itself. This approach is consistent with technology research outside of special education and has yet to address the fine-grained effects of visual information and hypermedia on cognitive processing for students with disabilities (see Kozma, 1991; Mandl & Levin, 1989; Nix & Spiro, 1990).

A common question that arises from this research is to what extent the overall findings from over a decade of research suggest differential effects of technology-based interventions for students with disabilities. After all, one of the main intentions of special education is to address individual differences. Hence, it is reasonable to ask whether or not there are technology-based approaches that are particularly suited to the unique needs of students with disabilities.

Answers to this question are more complex than one may anticipate. The expert systems research by Hofmeister and his colleagues (Geldern et al., 1991; Hofmeister, 1986; Hofmeister & Ferrara, 1986; Parry & Hofmeister, 1986) addresses this question directly through identification systems that are based on the disability criteria codified in state-level guidelines and the human judgments that often enter into eligibility decisions. Their work is a manifest case of technology use that is specific to different special education categories.

CBM systems designed by Fuchs and her colleagues (L. Fuchs et al., 1989; L. Fuchs et al., 1993; L. Fuchs, Fuchs, Hamlett, & Ferguson, 1992; L. Fuchs et al., 1991) allow teachers to track a student's academic progress irrespectively of disability categories. While CBM systems are not designed to distinguish the effects of interventions on different types of learners (e.g., average ability, emotionally disturbed, learning disabled), this effort satisfies one of the fundamental concerns of special education: attention to individual differences.

Other answers from the special education technology research over the last decade are either difficult to discern, because of the nature of the research, or equivocal. In many instances, experimental research frequently involves students of the same disability category. These studies examine the effects of specific instructional design variables rather than how these design variables, in conjunction with categorical variations (e.g., average ability, learning disabled, mentally retarded), might suggest that one type of technology-based instruction is best suited for students in a particular disability category. Instead, instructional design variables such as feedback and explicit strategies are often assumed to be particularly effective for special education students with learning problems based on established studies outside of a technology research agenda.

Studies in which a range of students from different special education categories or academic abilities have participated have yielded results that are mixed at best. More often than not, there have been few or no effects between groups (Bridges, 1996; Thorkildsen, 1989; Wizer, 1995; Zimmerman, 1988). In cases where there are differential effects between students with and without disabilities, there is

often the fundamental confounding that Clark (1983) noted between technology and instructional methods (see Podell et al., 1992; Vaughn, Schumm, & Gordon, 1992).

These findings reflect basic problems that the field of special education has faced for decades regarding identification of—and services for—students with mild disabilities. Research has demonstrated that the criteria for identifying students with learning disabilities vary considerably within and across states (Moats & Lyon, 1993; Ysseldyke et al., 1983) and that the quality of academic interventions for these students differs only marginally from that of interventions for students without disabilities in general education classrooms (Ysseldyke, O'Sullivan, Thurlow, & Christenson, 1989). Finally, others (e.g., McKinney, 1989) suggest that there is a significant developmental relationship between learning disabilities, attention disorders, and social-emotional problems, which makes practical distinctions between some mild-disability categories tenuous. It would appear that as long as special education technologists continue to use natural settings (e.g., public school classrooms) for research, there will be considerable problems in discerning which technology-based interventions are most appropriate for specific categories of students with mild disabilities.

A final question that arises from this literature is related to the generally practical focus of special education research. The field has long been concerned with interventions that make a substantive difference in daily practice. Recent calls for special educators to reexamine the relevance of any educational research that is not results oriented and consumer driven (Carnine, 1997) underscore this type of thinking. Most certainly, this concern is relevant to technology-based research in special education, and two issues appear to inhibit the practitioner's wider use of computers and other technological tools.

First, many of the technologies described in this research review were prototypic in nature. While they were robust enough to use in experimental studies, either they were not marketed commercially or they did not achieve sufficient visibility because of the narrowness of the special education commercial market (see Woodward & Noell, 1993). As a consequence, much of this special education technology rarely ever made it beyond the research or beta phase of development.

Second, a wide array of technology-based efforts have been guided by fundamental assumptions about teachers and teaching which were likely to have been in conflict with the special educator's essential vision of his or her craft. Cuban (1993) has cogently argued that claims about the underuse of technology in schools because of logistical difficulties or a lack of funds, for example, are only partial explanations of a deeper problem. Instead, many visions of how technology should be used in the classroom—ones that often stem from the research community—have been at cross purposes with core visions of teaching.

Thus, comprehensive approaches to instruction such as those that attempt to encode direct instruction techniques within tamper-proof software (e.g., G. Johnson et al., 1987) or videodisc programs (e.g., Kelly et al., 1990) conflict with the more informal and spontaneous instructional decision making that occurs in a classroom. Naturalistic research on technology use in special education corroborates this point, showing that even the most optimally designed software, for example, can be of limited benefit because of the everyday conditions of teaching. Observations and interviews of special education teachers indicate that CAI programs

are often used for motivational purposes and not as a systematic means of increasing academic abilities (MacArthur & Malouf, 1991).

The struggle to adjust technology to the perceived needs of the teacher is also apparent in the work of the Fuchses and their colleagues (Deno, 1990; L. Fuchs et al., 1994; L. Fuchs et al., 1989). Early CBM systems were designed merely to remove the drudgery of recording and summarizing data. The main intent was to provide teachers with information that would in turn facilitate careful pedagogical decisions—how best to adjust a student's program of instruction. The most recent versions of CBM, however, automate this kind of decision making through highly scripted interventions that are generated by an expert system. This move toward more directive interventions is based on the view that teachers, on their own, generally do not use a wide variety of instructional strategies and need specific recommendations (L. Fuchs, Fuchs, Bishop, & Simmons, 1992).

Yet as D. Fuchs and Fuchs (1996) recently noted, the objective and expert nature of outside consultation clashes with the view that teachers are the best judges of who qualifies for special education or what kind of instruction needs to be done next. This observation pertains to expert systems for classroom observation (e.g., Greenwood et al., 1994) as well as those designed to improve decisions as to who qualifies for special education services (Hofmeister et al., 1994). Comparable problems arise with constructivist approaches reviewed in this article, as these researchers attempt to move special educators from a traditional focus on specific skills to more integrated and student-directed approaches.

For special education technologists, all of this suggests that productive future research could be conducted in the areas of school culture and professional development. Yet the argument that teachers resist technology because of fundamental and conflicting visions of technology is complex in special education. Unlike the general educator whom Cuban (1993) had in mind, the special educator has multiple and competing roles. In addition to teaching, the special educator helps assure that students are eligible for services and monitors progress toward IEP goals. Effectively implementing and managing technology presents significant challenges for a single teacher who often designs and provides services for a wide range of students with disabilities. These demands, which are understandably beyond the scope of Cuban's analysis, may actually lead to significant uses of technology because of the need to make one or more dimensions of the practitioner's job more efficient, if not more sensitive to the highly individualized nature of special education services.

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